GOBIERNO DE ESPAÑA | MINISTERIO DE CIENCIA E INNOVACIÓN

Hidden sectors with two-particle angular correlations at e^+e^- colliders

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XUNTA DE GALICIA

Outline

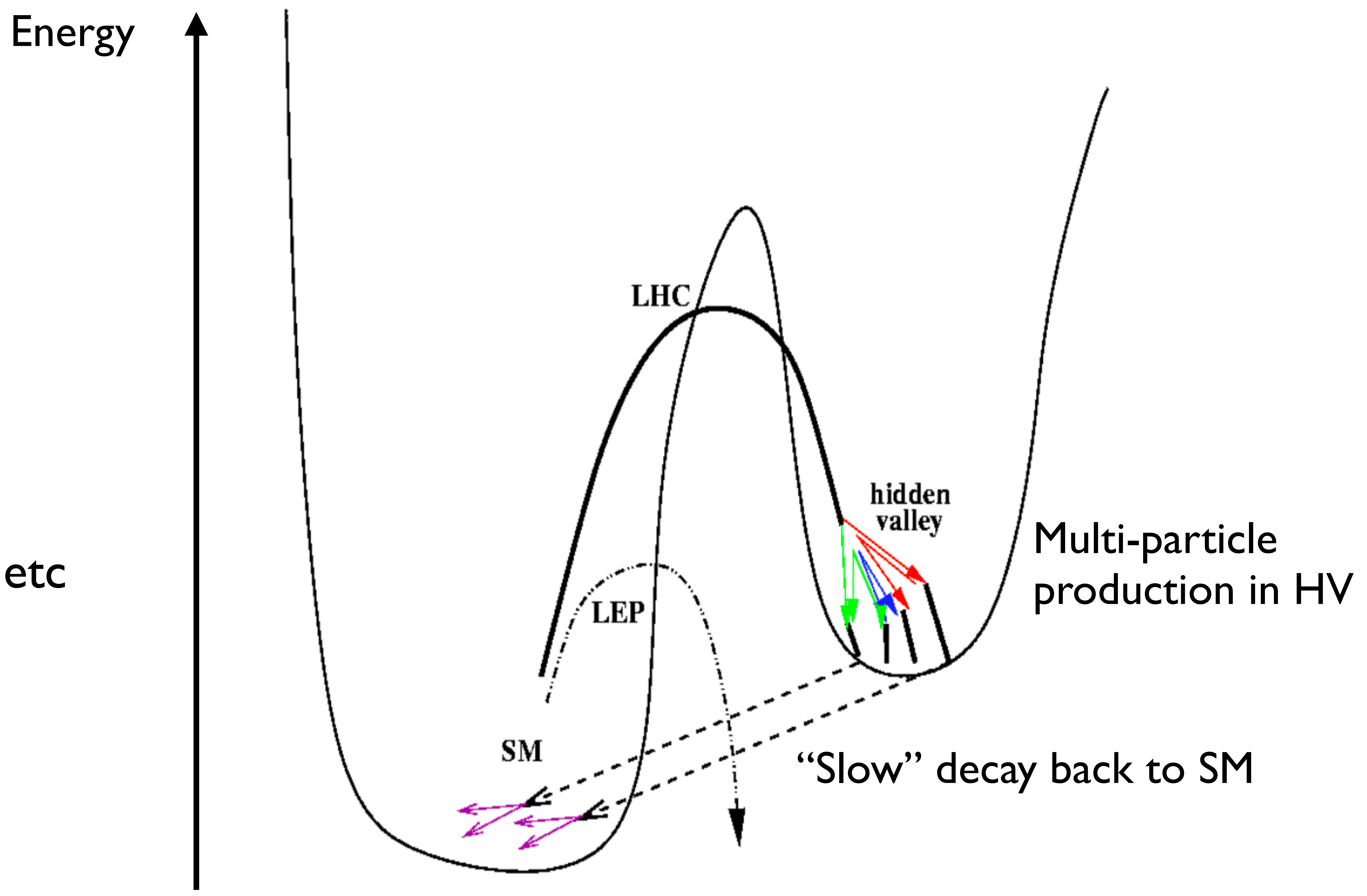
1. Hidden Valley models
    1. Which problems do they solve?
    2. Phenomenology
2. Future e+e- colliders: ILC and ILD
3. Particle correlations
4. Exploring HV with 2PC at e+e- colliders
5. Results and sensitivity
6. Conclusions

Hidden valley models (HV)

<u>Family of models with a basic structure</u>
- Another sector (v) is proposed
  - Accessible via higher energy process
- Coupled to SM via mediators
- Consequence:
  - Multi-particle production in the v-sector
  - Exceptionally busy final states

<u>Why the Hidden Valley Scenario?</u>
- Extra sectors often appear in string theory, SUSY breaking, etc
- Dark Matter candidate with weak parameter constrain

<u>Our approach:</u>
  - Find HV signatures as generic as possible
  - Help detector design at future colliders



The QCD-like SU(3) HV model will be considered in this talk

Implemented in PYTHIA

“Echoes of a hidden valley at hadron colliders”.Matthew J. Strassler a, Kathryn M. Zurek, Physics Letters B, Volume 651, Issues 5–6, 2007.

Hidden valley models (HV)

Standard model

SU(3)XSU(2)XU(1)

⟷

Communicator

Z', Higgs, SUSY LSP
sterile neutrinos…
O(TeV) scale

⟷

Hidden Valley

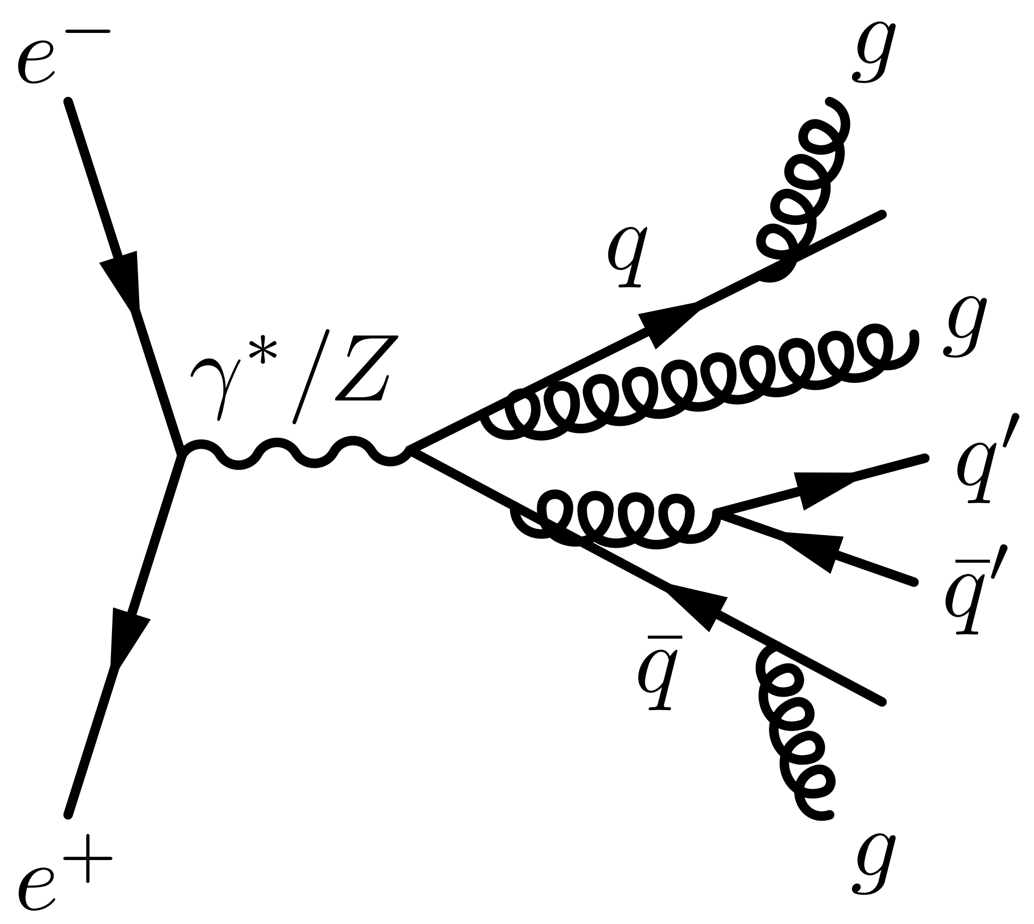
Gv

O(GeV) scale matter

We can study this with two particle correlations (2PC)

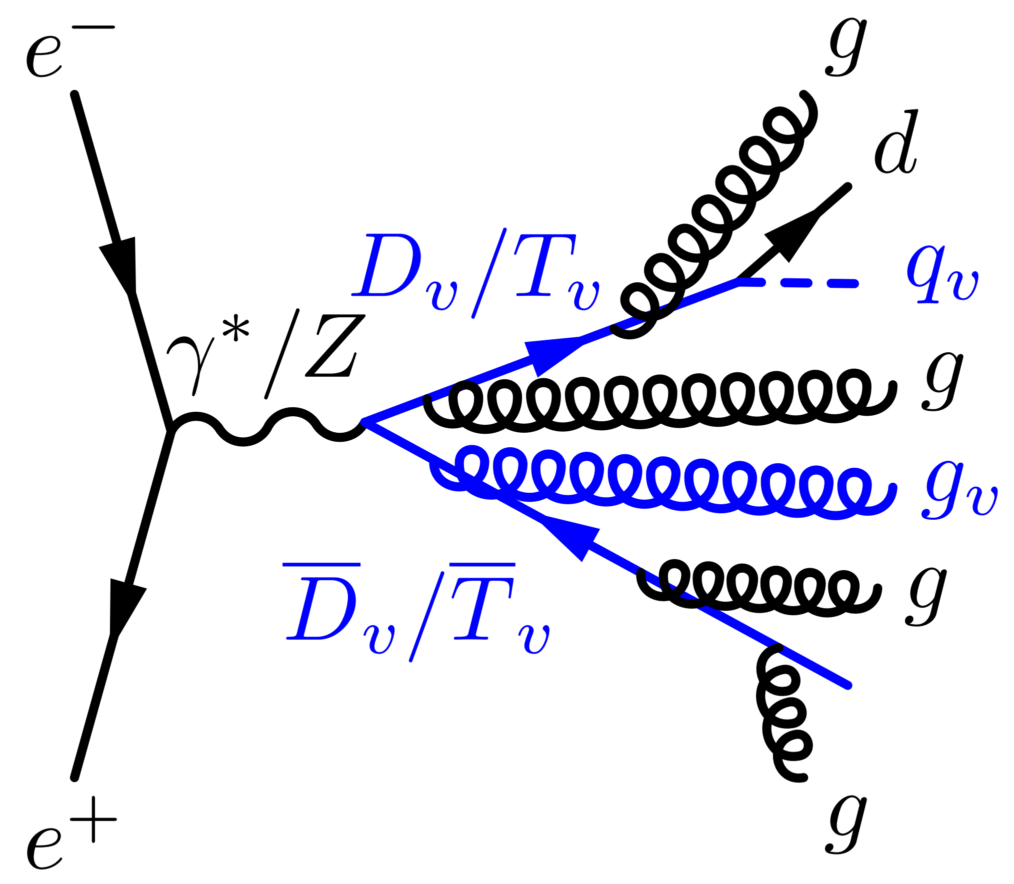
What happens in e+e- collisions ?

Background



SM e+e- anihilation

Signal



HV e+e- anihilation

Future e+e- colliders and experiments

Many interesting ideas for future e^+e^- colliders: CLIC, FCCee, ILC

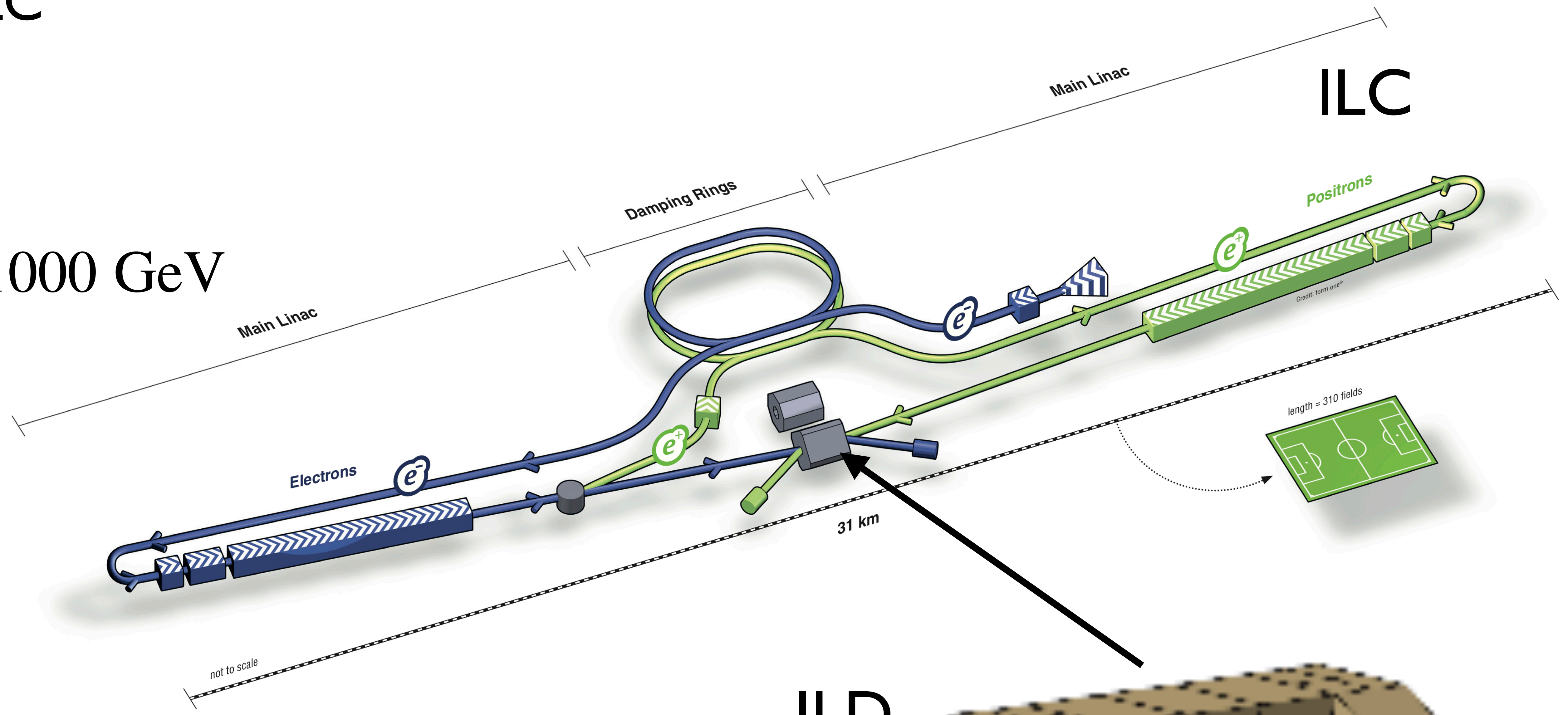
This talk is focus on the International Linear Collider (ILC):

- Longitudinally polarized e^+e^-
- Precise study of e^+e^- collisions at $\sqrt{s}$ = Z-pole,$250,500,1000$ GeV

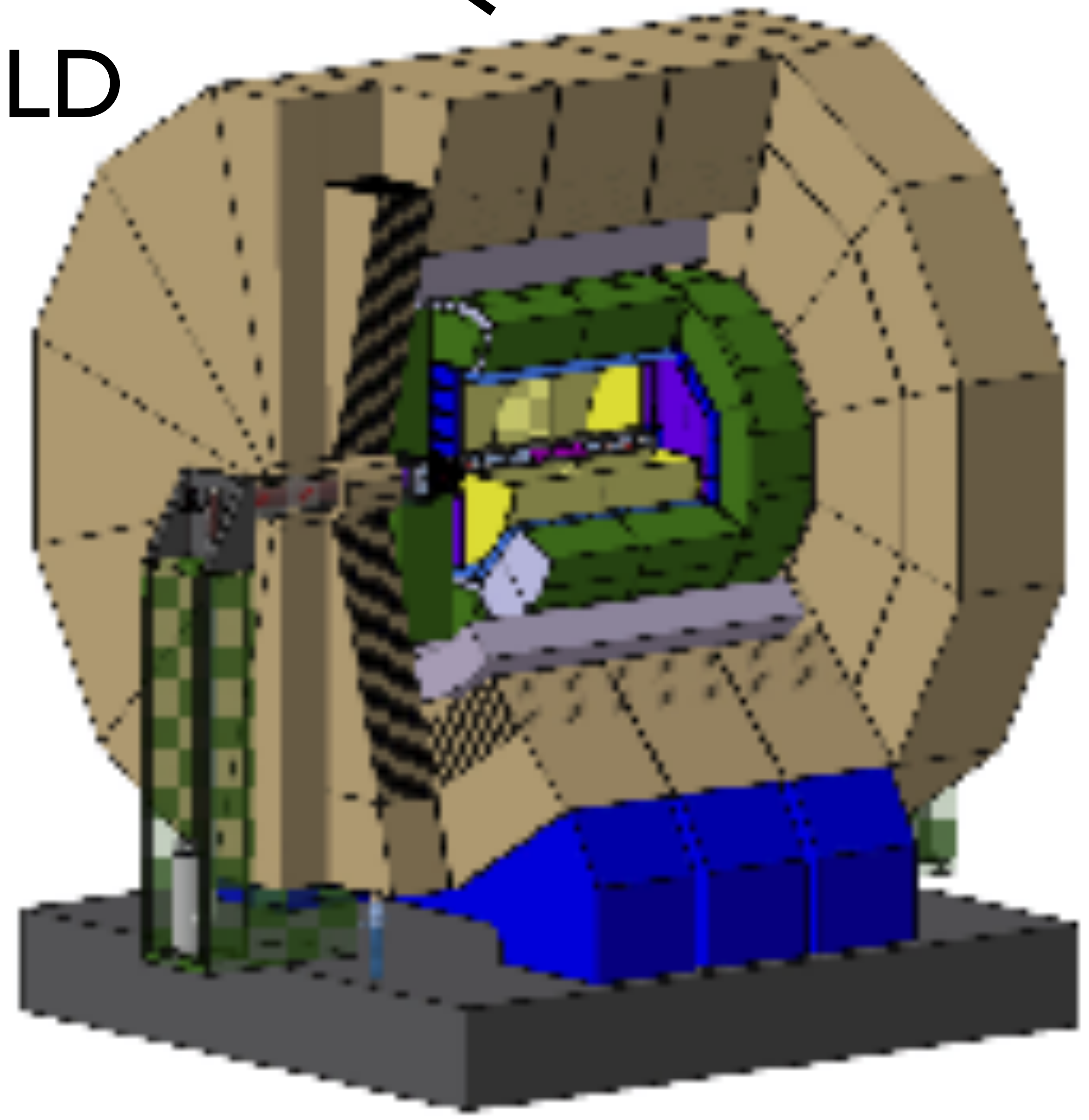
International Linear Detector (ILD):

- Inner silicon vertexing
- Silicon tracking systems
- Continuous 3D tracking and PID
- High granularity calorimeters within a 3.5 T solenoid
- Instrumented flux return used to identify muons

ILC



ILD



- First year data-taking integrated luminosity, $\mathscr{L}_{int} \simeq 100\ \mathrm{fb}^{-1}$
- Detector effects are studied with fast-simulation of the ILD detector models and the reconstruction tools of ILD software

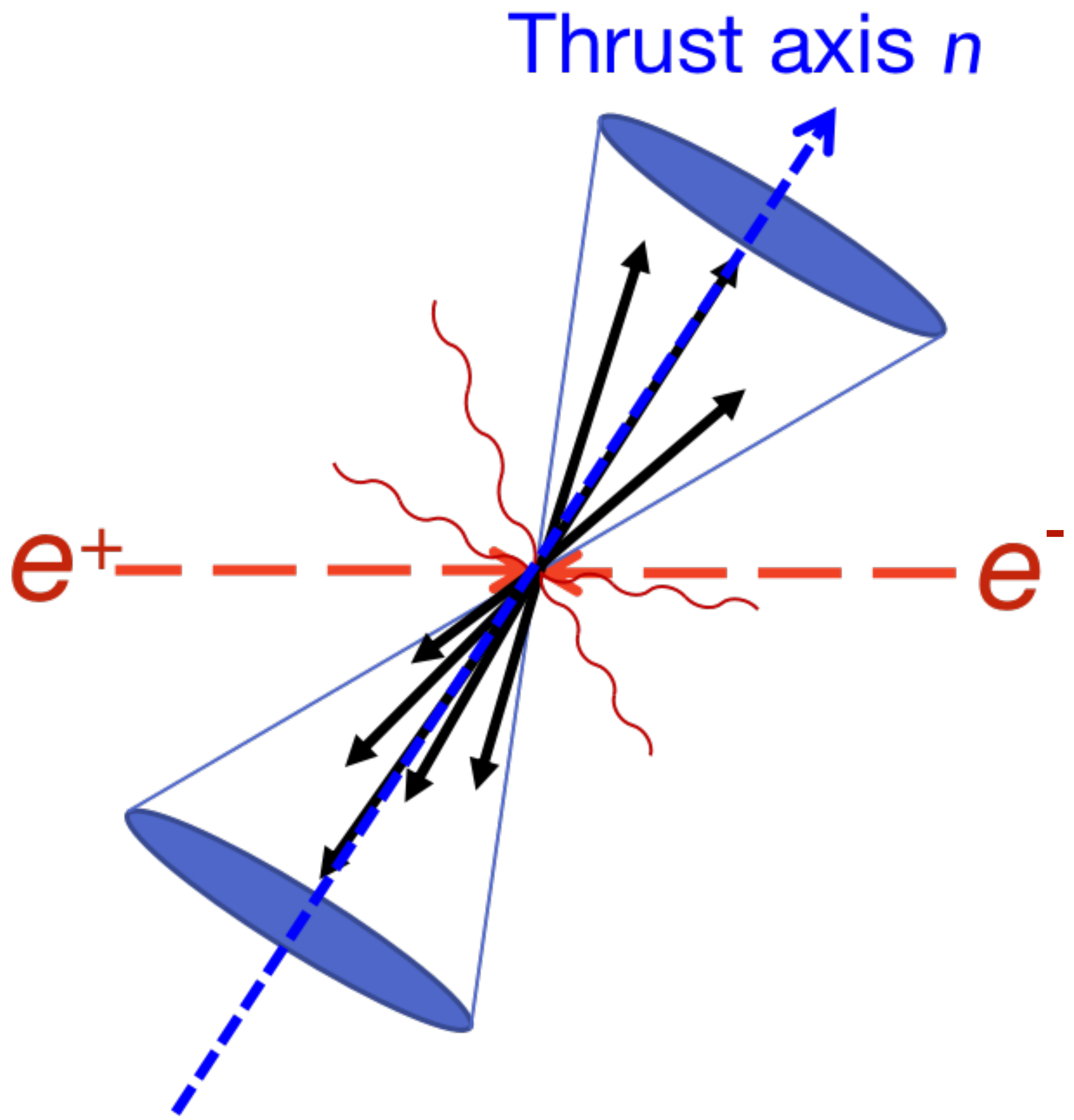
"The ILD detector at the ILC", ILD Collaboration, arXiv:1912.04601
"The International Linear Collider Technical Design Report". Maura Barone et. al. arXiv:1306.6352

Thrust axis in e+e- collisions

- Thrust axis (T) → Axis defined to study particles production in e+e-
  Align with the average momentum of the particles
  Well known since ALEPH

- Particle (η, ϕ) coordinates defined w.r.t. thrust axis

$$T = max(\vec{n})\frac{\sum_i |\vec{p_i} \cdot \vec{n}|}{\sum_i |\vec{p_i}|}$$



Two particle correlations: Definitions

2PC analysis is based on counting the number of particle pairs within a range of $(\Delta y, \Delta\phi)$

Correlation function:

$$C(\Delta y, \Delta\phi) = \frac{S(\Delta y, \Delta\phi)}{B(\Delta y, \Delta\phi)}$$

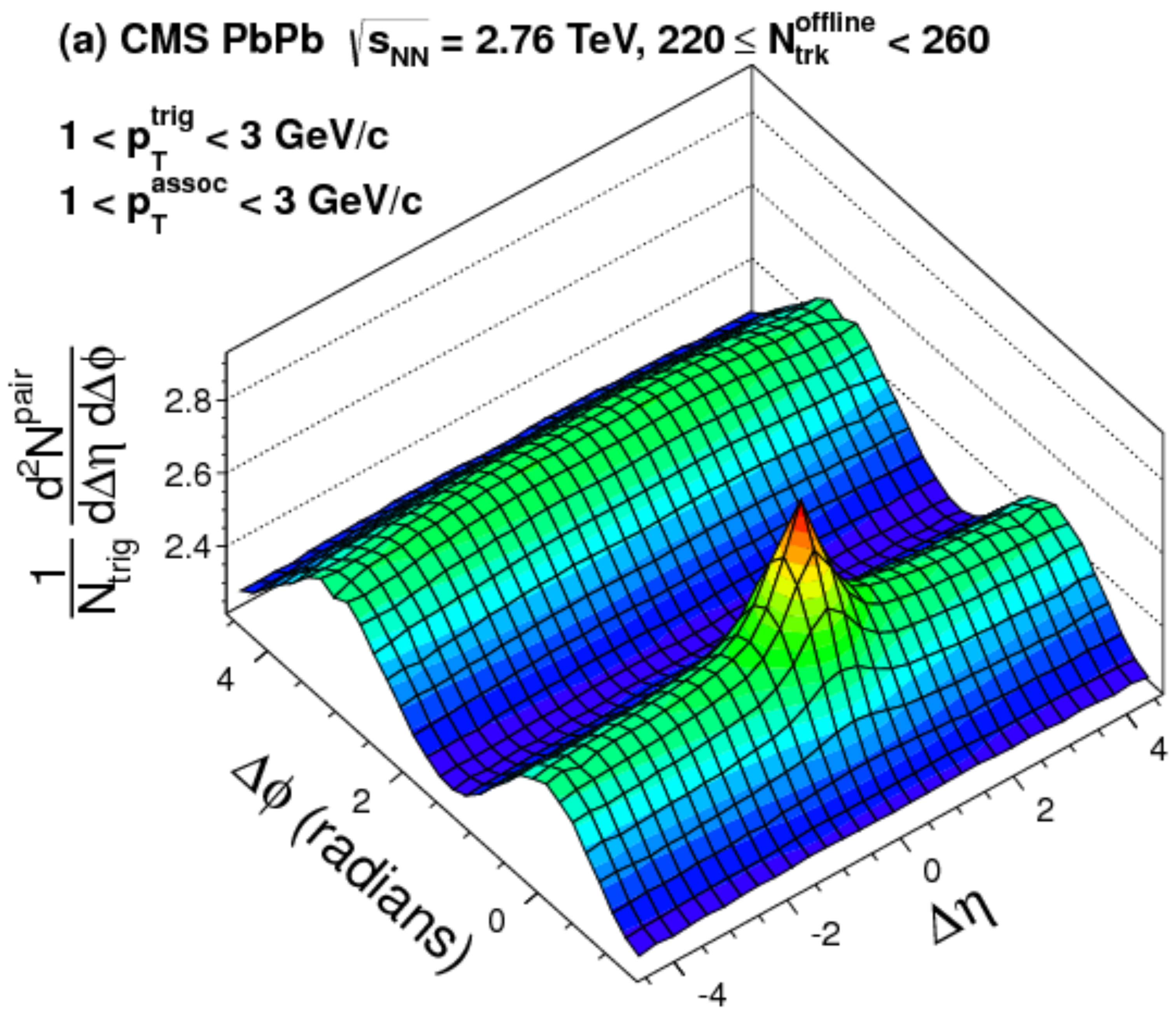
where $S(\Delta y, \Delta\phi)$ is the density of particle pairs within the same event

$$S(\Delta y, \Delta\phi) = \frac{1}{N_{pairs}} \frac{d^2N^2 same}{d\Delta y \Delta\phi}$$

and $B(\Delta y, \Delta\phi)$ is the density of particle pairs within different events

$$B(\Delta y, \Delta\phi) = \frac{1}{N_{pairs}} \frac{d^2N^2 mix}{d\Delta y \Delta\phi}$$

2PC function typical shape



Data selection: Improving signal/background

<u>Realistic selection optimization at detector level</u>

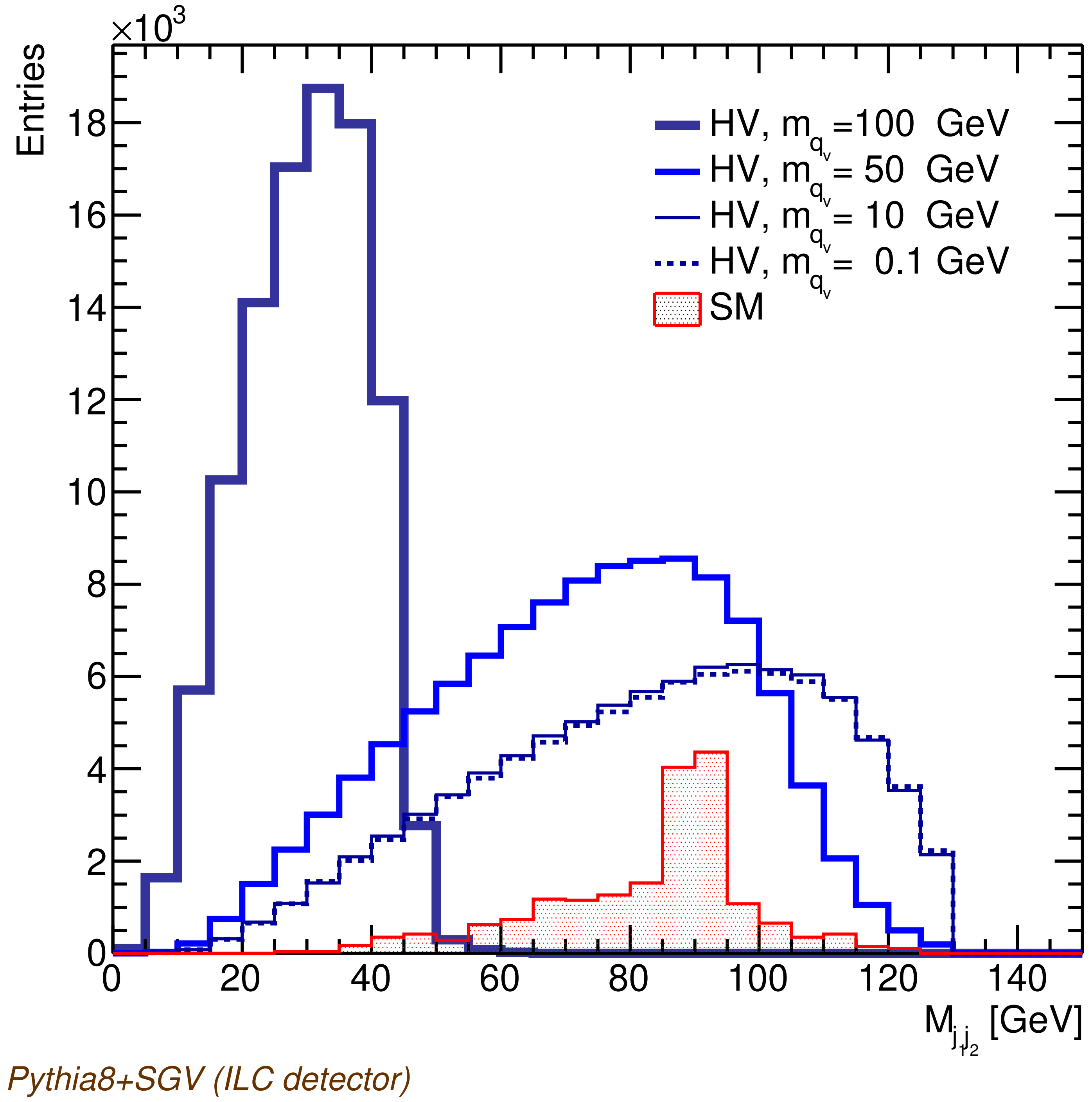
- number of PFOs*:
  charged < 22
  neutrals <15
  - Reconstructed ISR photons
    - $|\cos\theta_{\gamma ISR}| < 0.5; E_{\gamma ISR} < 40$ GeV
  - Di-jet invariant mass
    - $M_{jj} < 130$ GeV
  - Leading jet invariant mass
    - $M_j < 80$ GeV

TABLE I. Cross-sections for $e^+e^- \to D_v\bar{D}_v$ processes with different m_{q_v} masses, for $e^+e^- \to q\bar{q}$ and $WW \to 4q$ at $\sqrt{s} = 250$ GeV. The efficiencies of the selection criteria described in the main text, and the average charged-track multiplicity and its RMS, are shown.

Process	σ_{PYTHIA8} [pb]	Efficiency [%]	$\langle N_{\text{ch}} \rangle$
$e^+e^- \to D_v\bar{D}_v$			
$m_{q_v} = 0.1$ GeV	0.13	36	12.4 ± 3.7
$m_{q_v} = 10$ GeV	0.12	36	12.4 ± 3.7
$m_{q_v} = 50$ GeV	0.12	42	11.4 ± 3.5
$m_{q_v} = 100$ GeV	0.12	42	6.5 ± 2.1
$e^+e^- \to q\bar{q}$ with ISR	48	$\lesssim 0.01$	9.9 ± 3.4
$WW \to 4q$	7.4	$\lesssim 0.001$	–

Great efficiency suppressing SM background!

Di-jet invariant mass distribution for signal (HV) and background (SM)

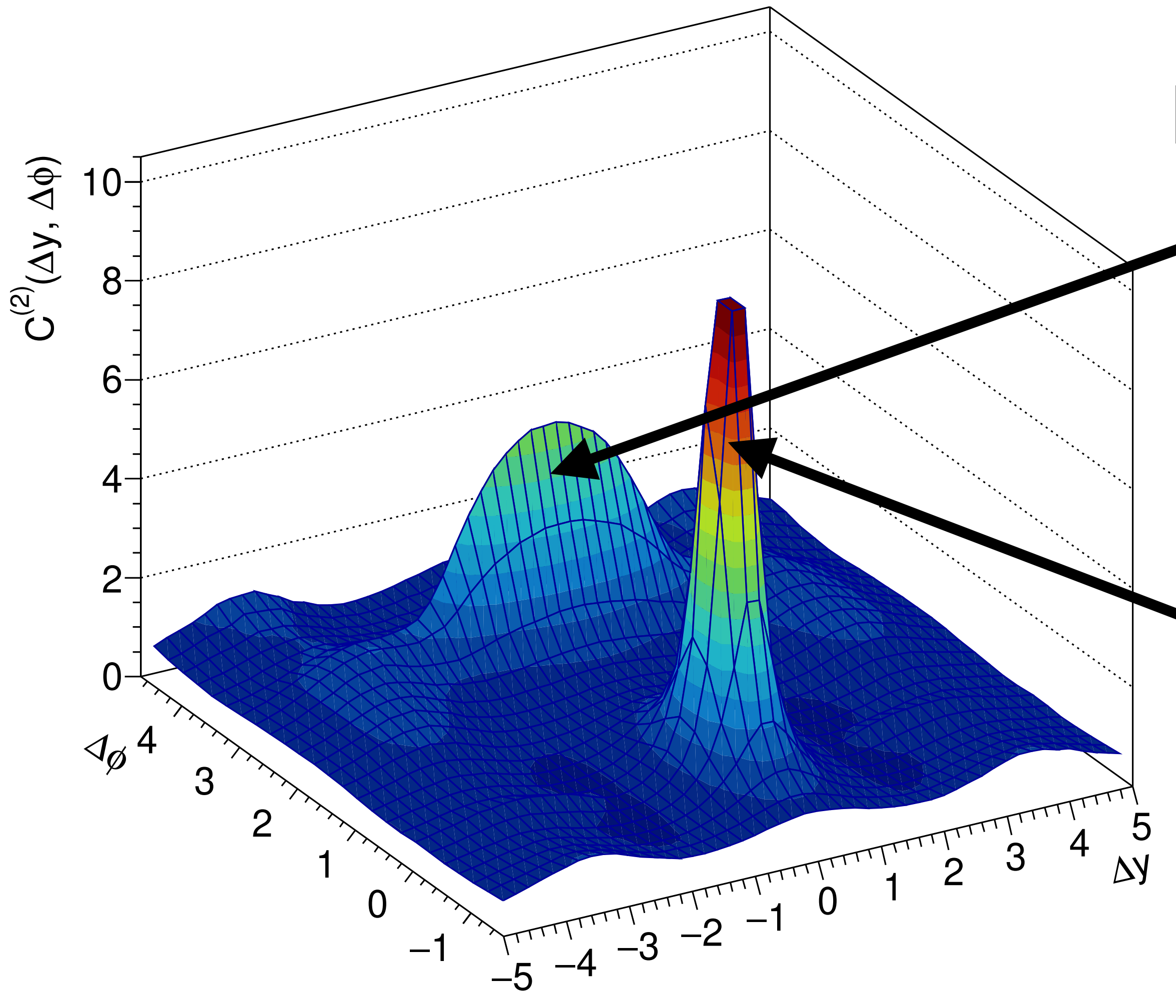


*PFOs: Particle Flow Objects. Detector level particle candidates in ILD software

Correlation functions

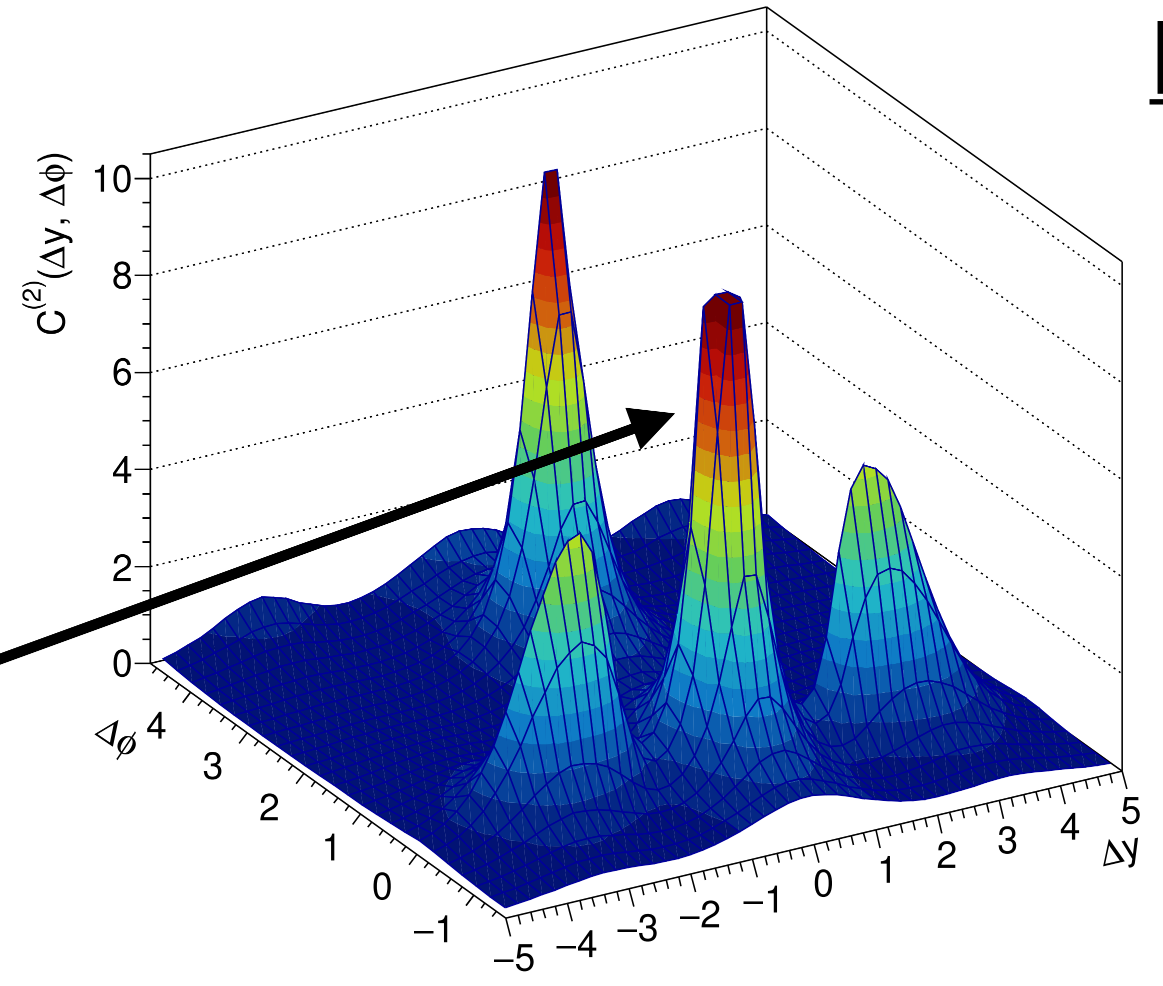
Before selection

Back-to-Back



SM

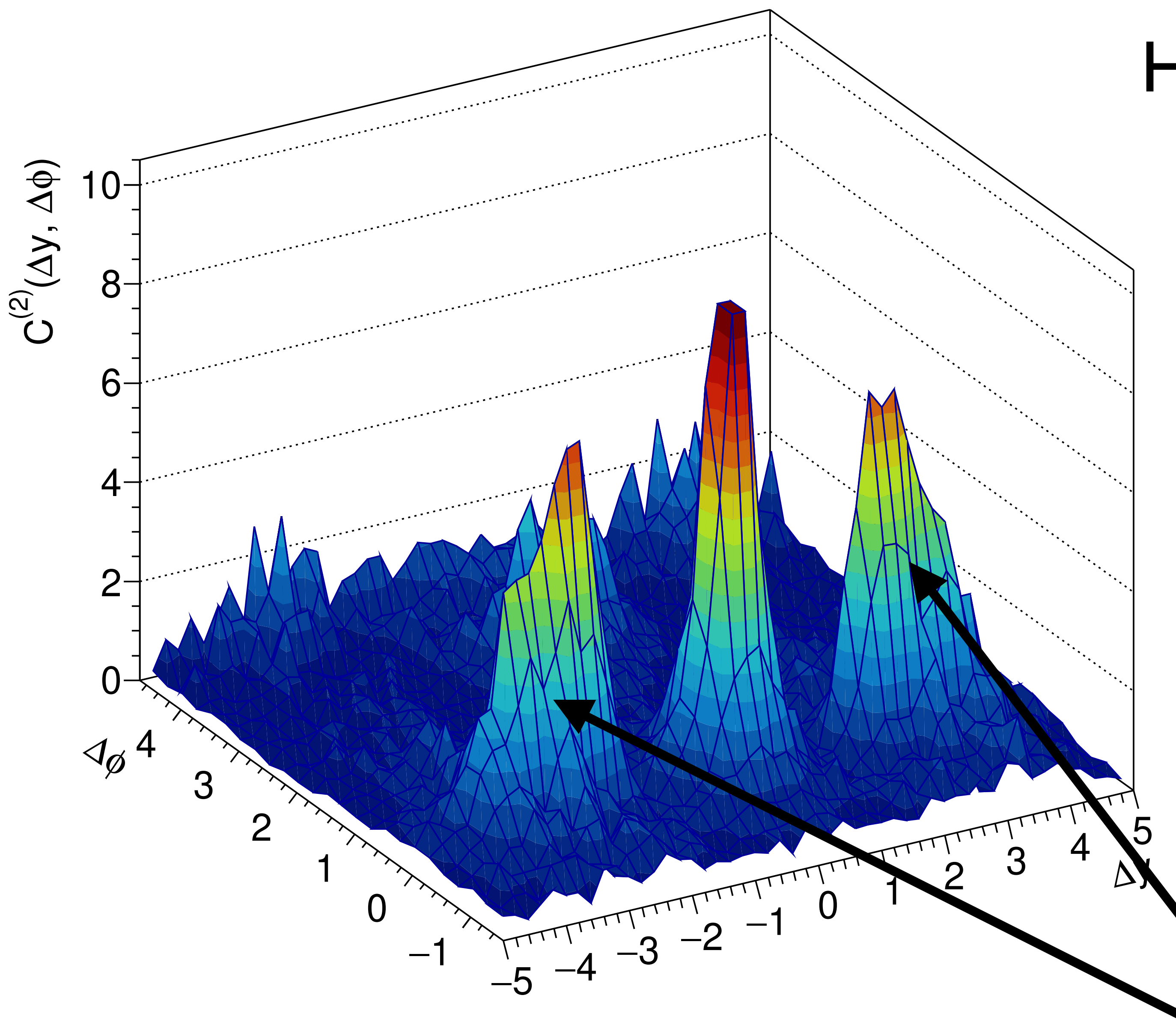
In-Jet pairs



HV $(m_{q_v}=100\ GeV)$

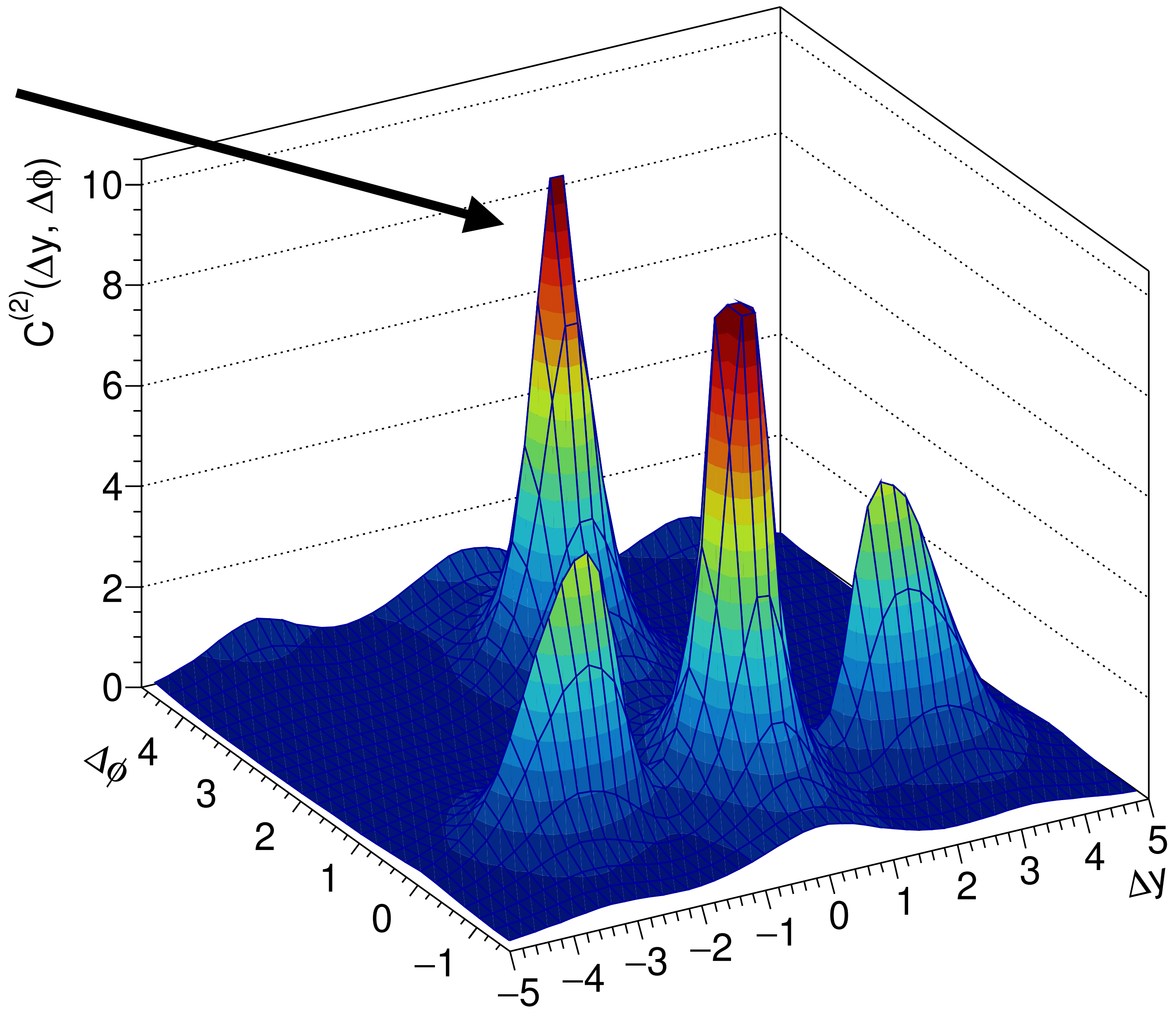
Hidden Valley signature

After selection



SM

ISR effect



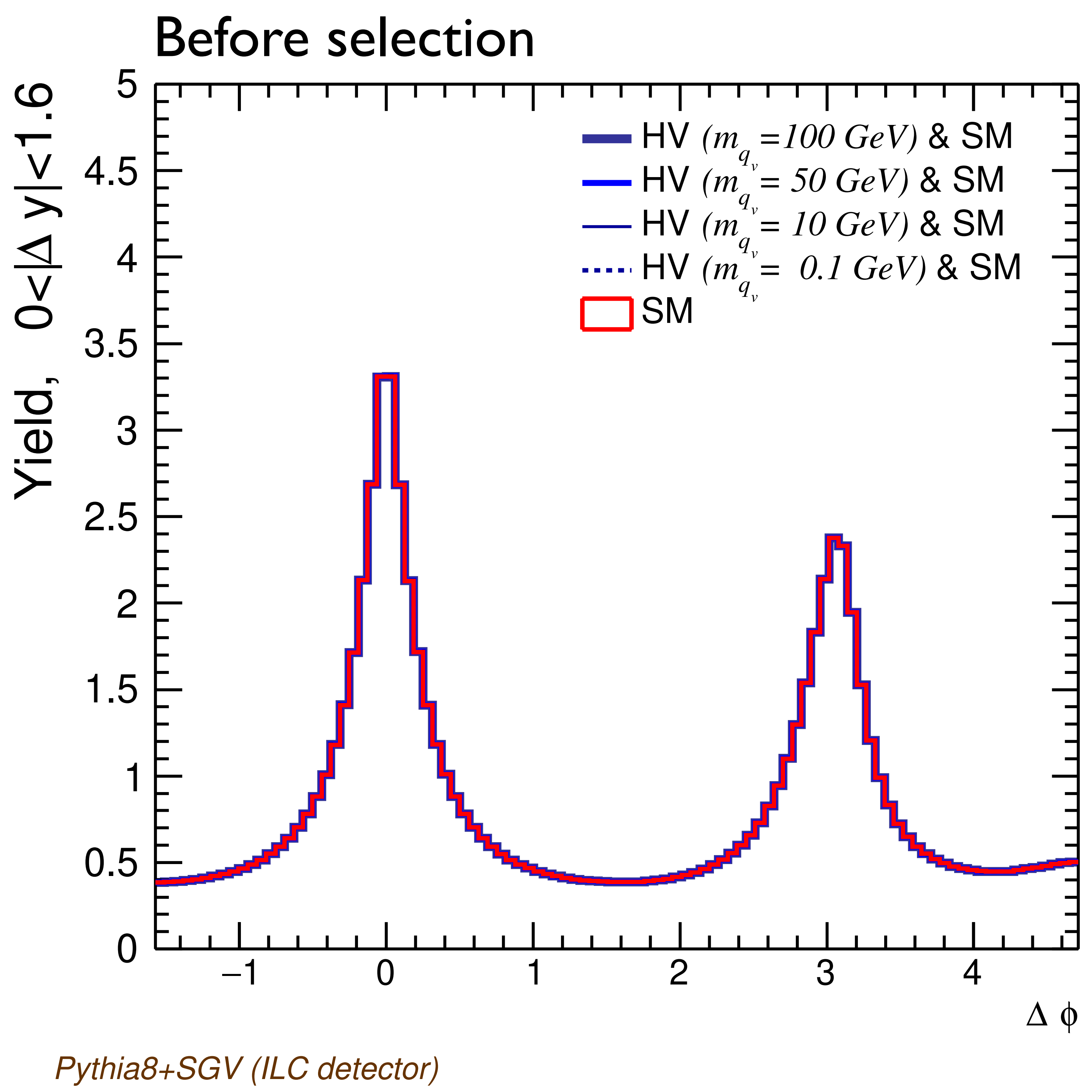
HV $(m_{q_v}=100\ GeV)$

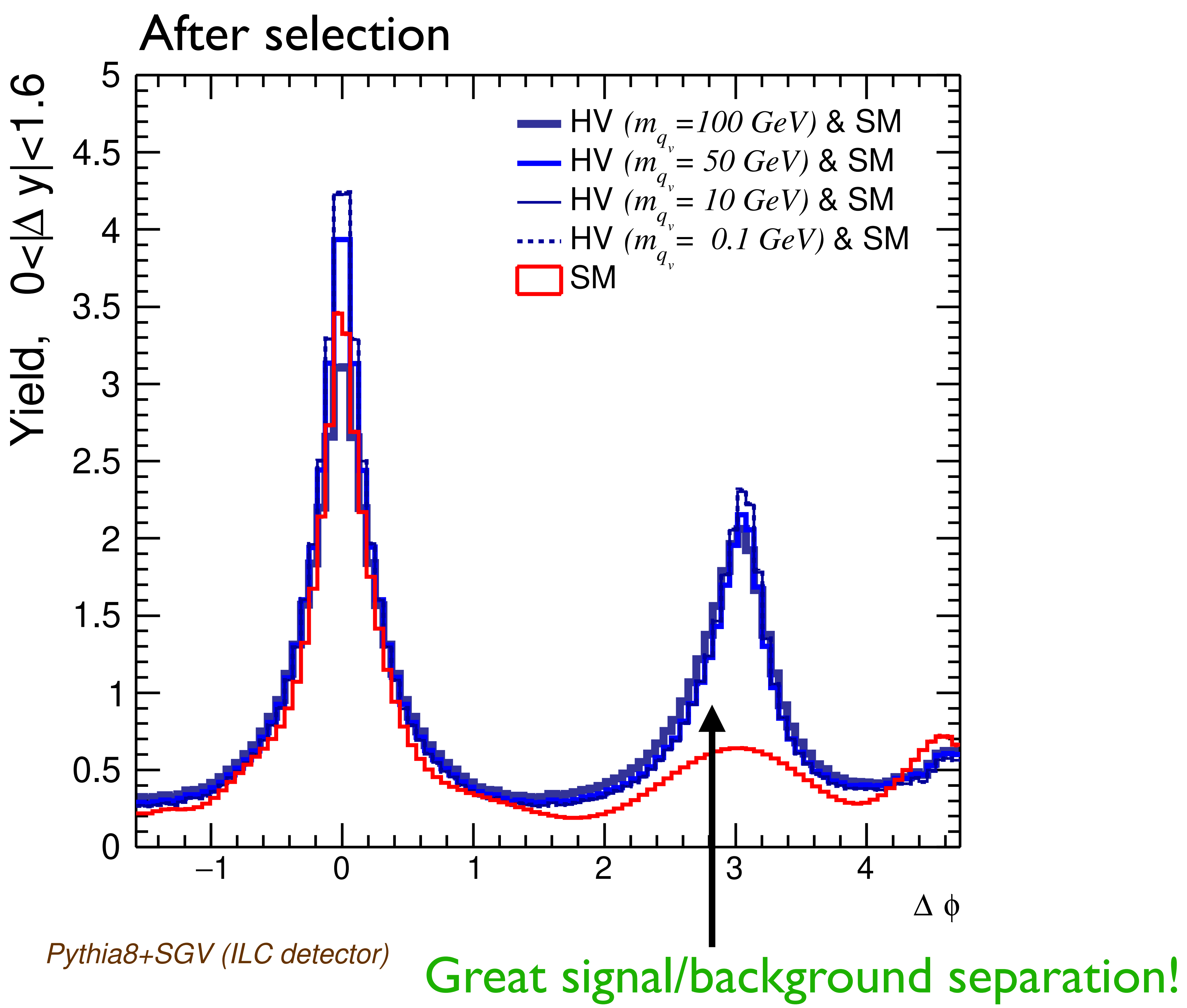
Yield and signal separation

The Yield, is just the integral of the 2PC function over a y range:

$$Y(\Delta\phi) = \frac{\int_{y_{inf} \le |\Delta y| \le y_{sup}} S(\Delta y, \Delta\phi) dy}{\int_{y_{inf} \le |\Delta y| \le y_{sup}} B(\Delta y, \Delta\phi) dy}$$

Applying our selection cuts → We reduce SM while keeping HV.
Yield becomes and observable for HV discovery



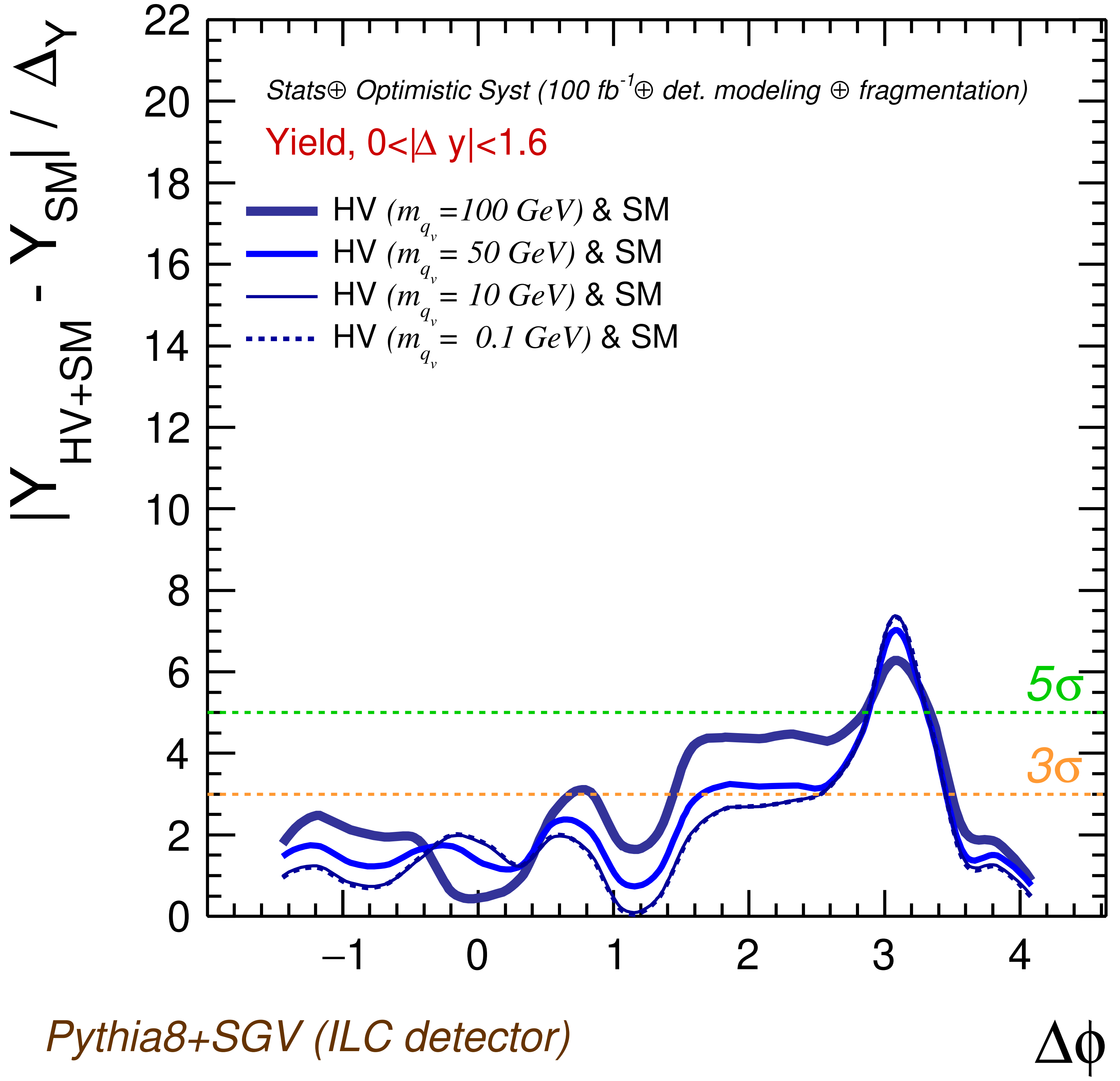


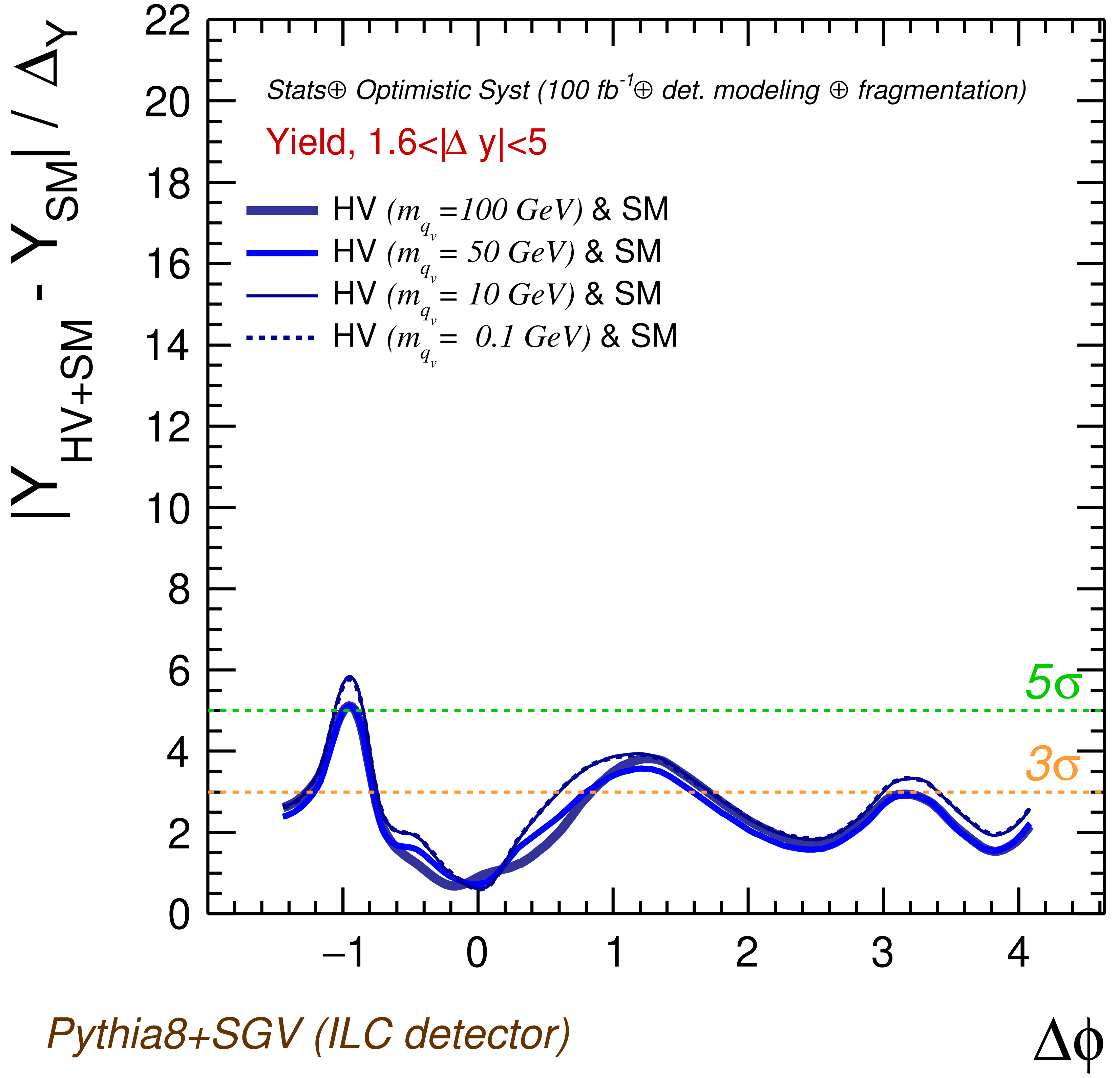
Uncertainties and sensitivity

Uncertainties:

- Statistical from luminosity: $\mathscr{L}_{int} = 100\ \text{fb}^{-1}$
- Parton Shower, Fragmentation and Hadronization : HERWIG vs PYTHIA
- Detector modeling: Efficiencies are partially (totally) cancel in 2PC studies. However, a conservative uncertainty is added

In this scenario, the sensitivity is $> 5\sigma$. However, there is room for improvement
Different hidden-quark (qv) masses does affect the sensitivity





Conclusions

- We propose a novel observable for new physics at e+e- colliders
- QCD like Hidden Valley model is studied variating masses using PYTHIA8
- Background studies and selection optimization → Filter 0.01% of SM events while keeping 40% of HV
- Detector effects and sensitivity studies → Current knowledge with first year of integrated luminosity give us $> 5\sigma$
- What about higher energies? An study of cross-section is done for $\sqrt{s} = 500$ GeV and 1 TeV

Process	$\sigma_{\sqrt{s}=500\text{GeV}}$ [pb]	$\sigma_{\sqrt{s}=1\text{TeV}}$ [pb]
$e^+e^- \to D_v\bar{D}_v$	$m_{D_v} = 250$ GeV 2.4×10^{-2}	$m_{D_v} = 500$ GeV 4.4×10^{-3}
$e^+e^- \to T_v\bar{T}_v$	$m_{T_v} = 250$ GeV 9.5×10^{-2}	$m_{T_v} = 500$ GeV 1.8×10^{-2}
$e^+e^- \to q\bar{q}$ with ISR	11	2.9
$e^+e^- \to t\bar{t}$	0.59	0.19
WW fusion	3.4	1.3

- Other channels appear:
  - $t\bar{t}$ production and WW fusion from the SM
  - $T_v\bar{T}_v$ in the HV sector
- Contribution from SM decreases with the energy
- A reduction of two orders of magnitude in the HV cross-section at $\sqrt{s} = 1$ TeV

References:

- "Prospects of searching for (un)particles from Hidden Sectors using rapidity correlations in multi-article production at the LHC". Miguel Angel Sanchis Lozano, International Journal of Modern Physics AVol. 24, No. 24, pp. 4529-4572 (2009)
- "Searching for hidden matter with long-range angular correlations at $e+e-$ colliders". R.Pérez-Ramos, M.A. Sanchis-Lozano, and E.K. Sarkisyan-Grinbaum, Phys. Rev. D 105, 053001 – 2022
- "Exploring hidden sectors with two-particle angular correlations at future e+e− colliders". E. Musumeci, A. Irles, R. Perez-Ramos, I. Corredoira, E. Sarkisyan-Grinbaum, V.A. Mitsou and M.A. Sanchis-Lozano. (2023) https://arxiv.org/pdf/2312.06526